Accelerator and Research reactor Infrastructures for Education and Learning

ARIEL

The Double-Energy Double-Velocity fission spectrometer VERDI

ARIEL-SANDA meeting (FINAL)

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European Commission

NEUTRONS FOR SOCIETY

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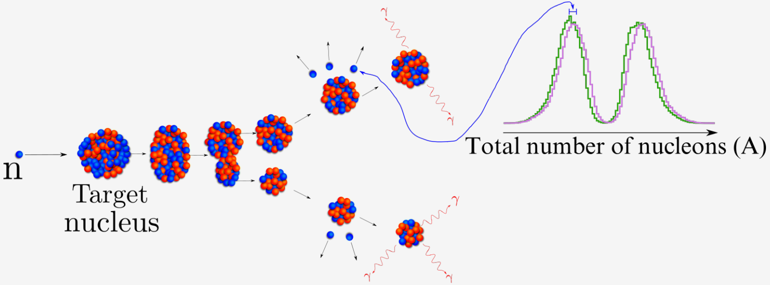
Outline

1. Introduction
   - Motivations to study nuclear fission
2. The fission spectrometer VERDI
3. Restart of operations of VERDI spectrometer (SV_1_2 and SV_5_2)
   - Energy resolution optimization
   - TOF resolution optimization
     - Assembly of new position sensitive MCP detector (SV_1_3, SV_1_4 and SV_5_9)
4. Investigation of the plasma delay time effect in PIPS detectors for the development of VERDI fission spectrometer (TAA_3_4)
5. Analysis and Results
6. Upcoming work



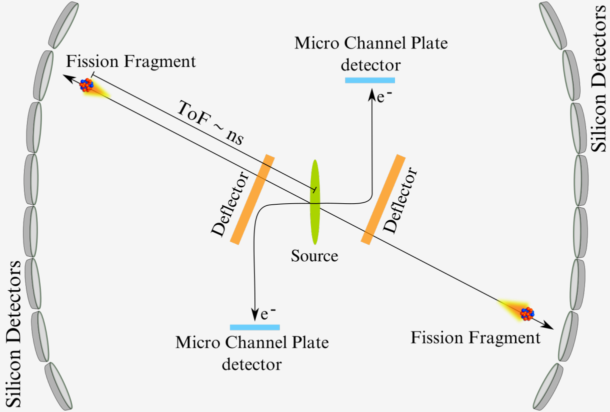
Fundamental The measurement of the fission yield mass distributions allows the understanding of fission dynamics.

Applications Generation IV nuclear energy devices based on fast-neutron spectrum are a call for more accurate nuclear data on the fission process (fission yields are less known in fast fission region).

How to measure fission yield mass distributions?

VERDI

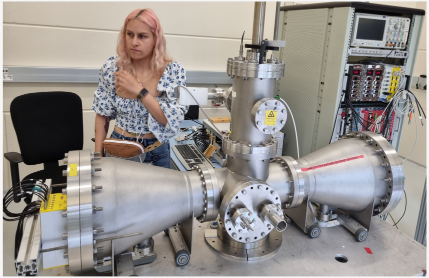
VElocity FoR DIrect particle identification



2E - 2v

$$A_{\text{post}1,2} = \frac{2E_{\text{post}1,2}}{v^2_{\text{post}1,2}}$$

$$A_{\text{pre}1,2} \approx \frac{v_{\text{post}2,1}}{v_{\text{post}1}+v_{\text{post}2}}$$



Scheme of VERDI spectrometer (left) developed at JRC (Belgium). Picture of VERDI setup (right).

Experimental work at JRC

Experimental work at JRC

The design goal of VERDI is to produce fission yield mass distributions with a mass resolution from 1-2 mass units, for which a combined TOF resolution of at least 100 ps and an energy resolution of at least 1 MeV is required. Therefore, the re-operation of VERDI came with a series of upgrades in the system to reach those values:

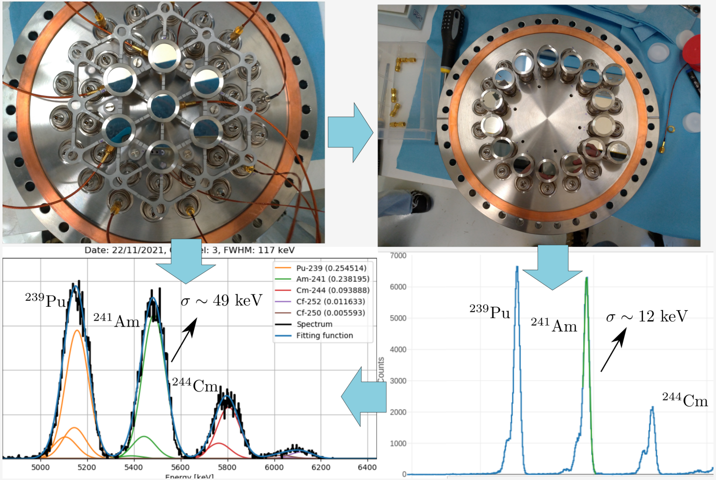
- New flange with 32 connections to optimize geometrical efficiency and new PIPS preamplification chains.
- New fully digital acquisition system with 2.5 GHz sampling frequency and 12 bits of resolution.
- New MCP system with position-sensitive capabilities
- New developed plasma-delay-time parametrization for data analysis correction.
- New PhD student visiting JRC for 1 year.

Upgraded nuclear outfit

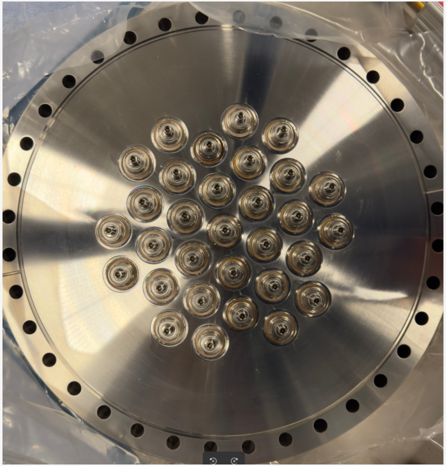
Energy resolution optimization

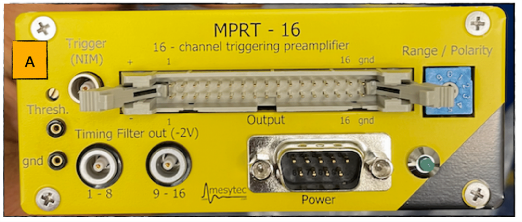
The PIPS detectors used in VERDI have a fabric resolution of $\sigma \sim 8$ keV. The aim was to reproduce it by trying different types of:

- Connection to the flange.
- Preamplification chains.
- Acquisition cards.
- The DSP was optimized using CRRC^4 filters, based on results of studies done at UU.

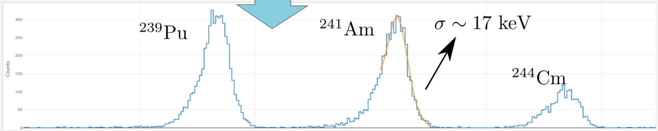


Energy resolution optimization

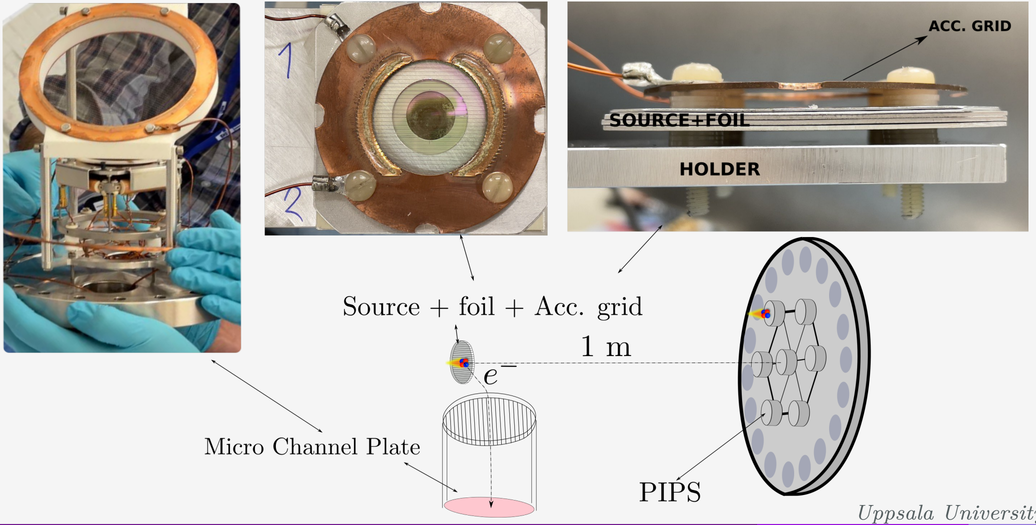




After optimizing detector attachment to the frame and connections



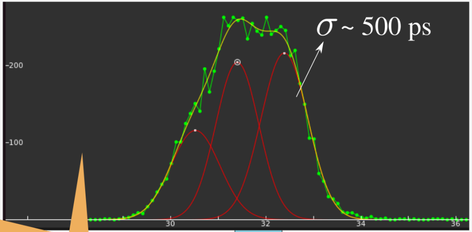
Timing resolution optimization
MCP system



Timing resolution optimization

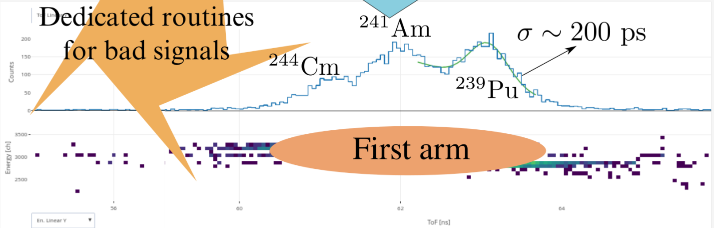
Testing timing resolution with old MCP system

The main objective of the visit SV_1_2 was to re-operate both arms of VERDI.

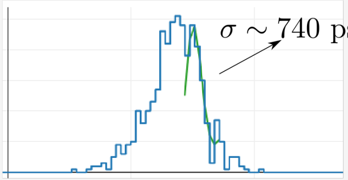


We aim to reach a TOF resolution of less than 200 ps

Dedicated routines for bad signals



First arm

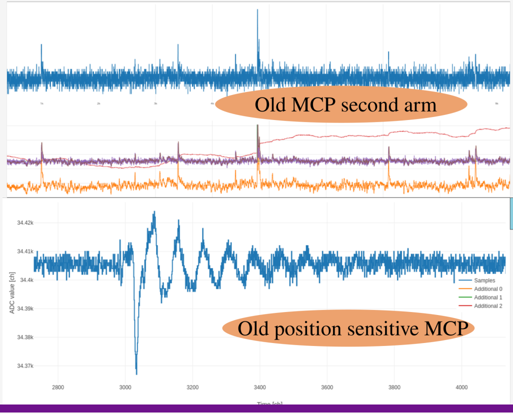


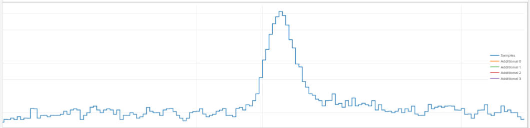
Second arm

Timing resolution optimization

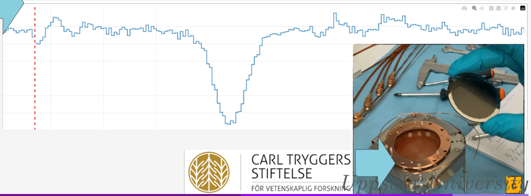
Assembly of new position sensitive MCP detector

The position-sensitive MCP signals (first arm) as well as the time reference MCP signals (second arm) had a very poor quality. A new position-sensitive MCP was purchased by UU for the second arm, which provided a TOF resolution of ~ 190 ps.





New position sensitive MCP



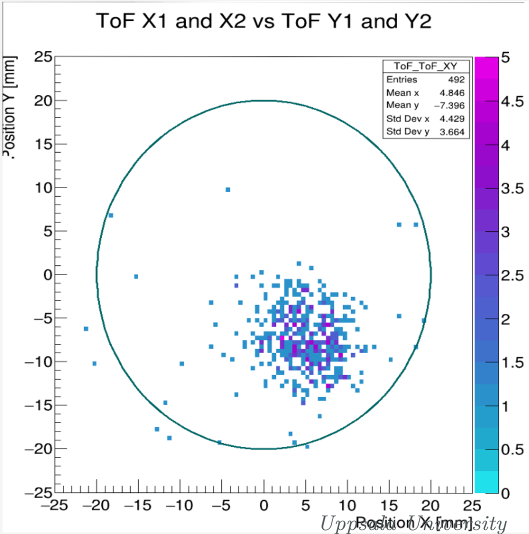
CARL TRYGGERS STIFTELSE
FÖR VETENSKAPLIG FORSKNING

Timing resolution optimization
Current status and upcoming work

- Some challenges in the coincident events statistic delayed the characterization of the new MCP.
- A new software to trigger the cards with the PIPS signals was tested showing successful results in the coincident events statistics.

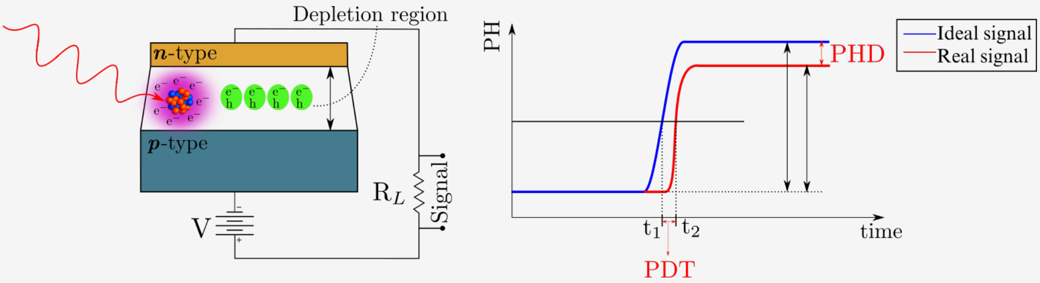
Upcoming work.

- A technical paper to report the results of the upgraded VERDI setup is foreseen.
- An experiment with Cm is planned for spring 2024, once all the technical remaining work is finished.



Plasma-induced effects in silicon detectors

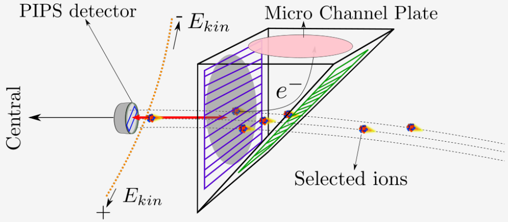
Plasma effects in silicon detectors



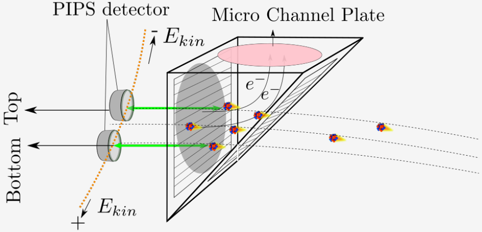
Representation of the Plasma Delay Time (PDT) and Pulse High Defect (PHD) on a silicon PIPS detector.

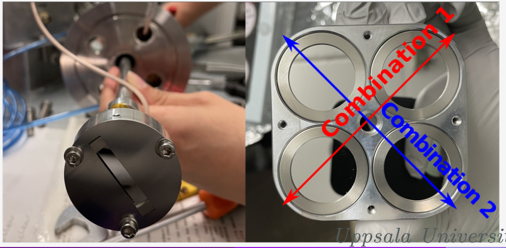

Experiment at Institute Laue-Langevin

Experimental campaign at ILL
Setup



Preamp II	Top I	Combination 1
	Top II	Combination 2
Preamp I	Central I	
	Bottom I	Combination 1
	Bottom II	Combination 2

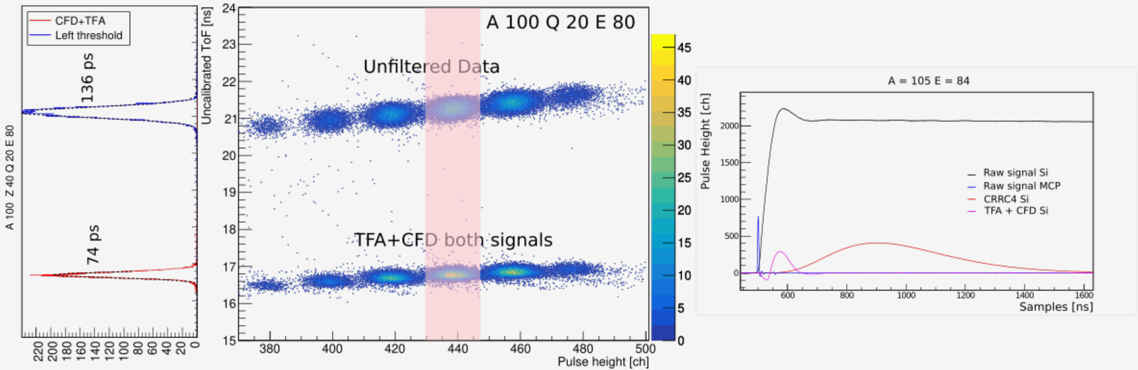




Analysis

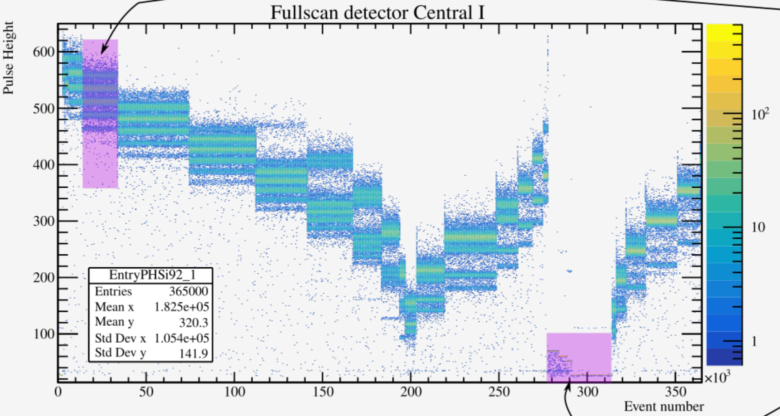
Combined ToF resolution

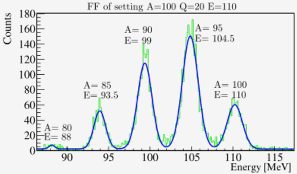
Timing Filter Amplifier + Constant Fraction Discriminator filters were applied to the signals.



For the energy resolution CRRC^4 filters were used (1 MeV to 2 MeV for FFs).

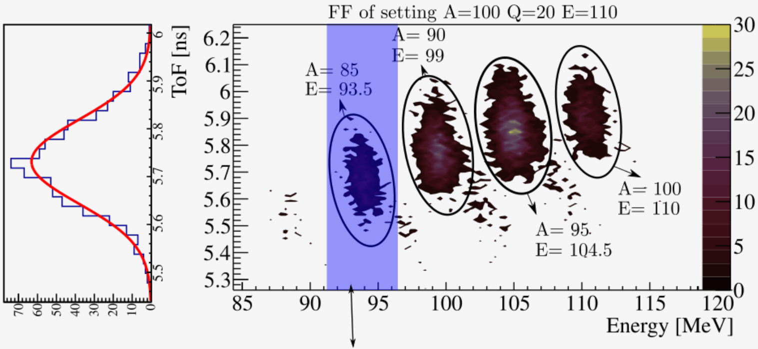
ToF and energy-channel calibrations





PDT and PHD estimated values are relative to α-particles with different energies (4.75, 12 MeV, 10.5 MeV, or 9 MeV

α -particles



Cuts in energy were used to select each mass in the setting and projection to the ToF axis.

The difference between the measured and calculated ToF is attributed to the PDT.

$$\text{PDT} = ToF_{\text{measured}} - ToF_{\text{true}}$$

Analysis
Pulse High Defect extraction

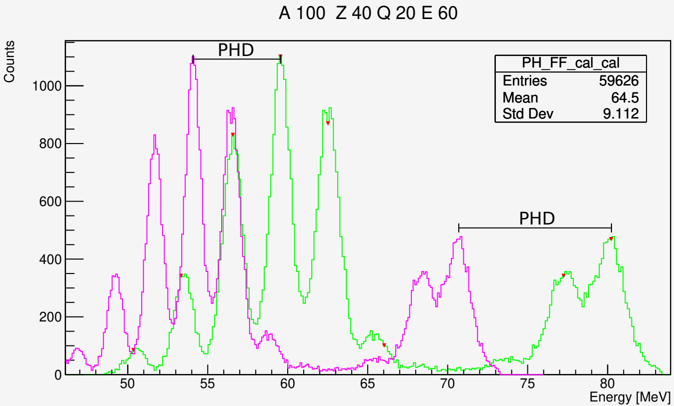
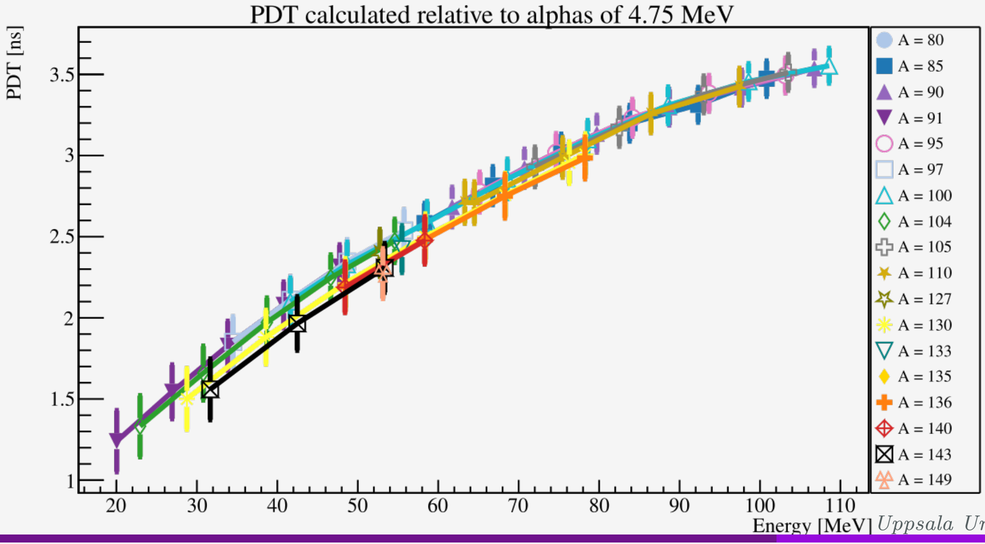
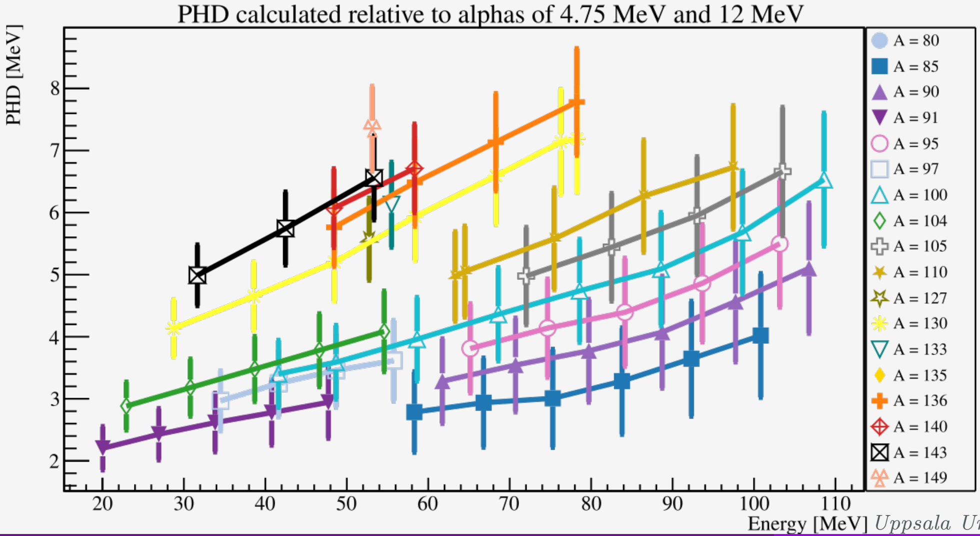


Figure: Spectrum calibrated with alphas (magenta) and spectrum adjusted to LOHENGRIN energies (green). To extract the PHD value we substract the LOHENGRIN energies with losses (simulated with Geant 4) from the measured energies.

Results
PDT trends

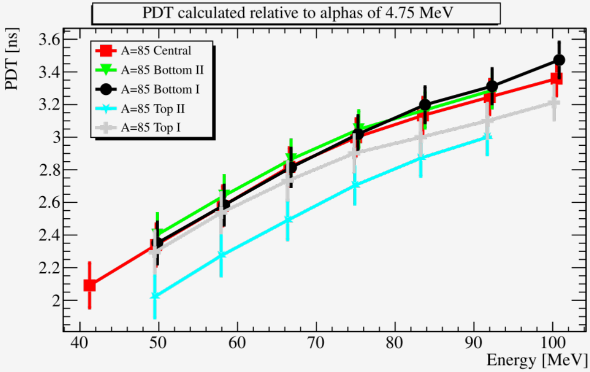


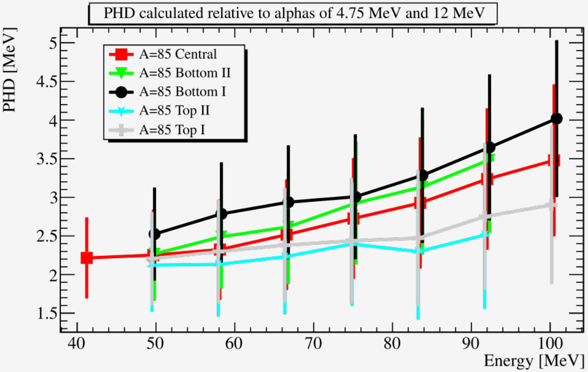
Results
PHD trends



Results
Interdetector comparison

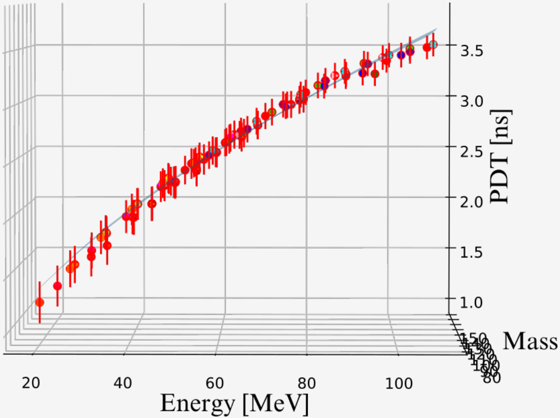
→Interdetector comparison of PDT and PHD for A = 85. PDT results are in good agreement for detectors connected to the same preamplification chain.





RESULTS
MODELING

$$\text{PDT(A,E)} = C \cdot \text{A}^{N_0}\text{E}^{N_1} \qquad (1)$$



Fit parameters result from the two-dimensional fit using equation (1) to the PDT data of each detector.

Detector	C	N_0	N_1
Bottom I	0.315(26)	-0.064(14)	0.586(08)
Bottom II	0.327(35)	-0.029(20)	0.543(10)
Central I	0.315(31)	-0.043(18)	0.562(08)
Top II	0.284(40)	-0.015(25)	0.548(13)
Top I	0.342(35)	-0.077(19)	0.583(09)

Upcomming work

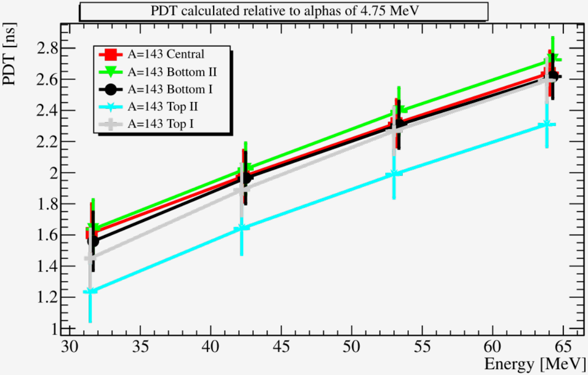
Upcoming work

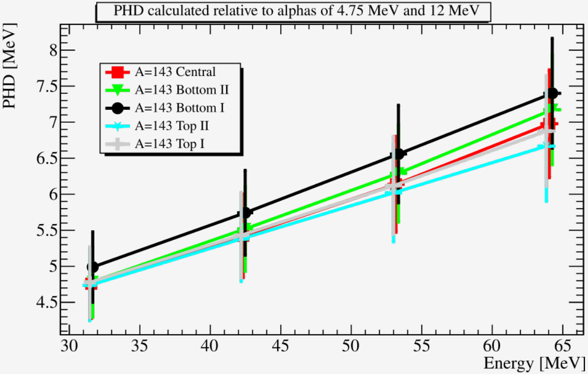
1. A paper is foreseen from the data analysis of old VERDI data of ^{252}Cf(sf) in which the newly developed parametrization will be verified.
2. The parametrization will be also used in the Cm experiment data analysis.
3. These results will be part of my PhD thesis dissertation in 2025.

These projects have received funding from the Euratom research and training program 2014-2018 under grant agreement No. 847594

Thanks

→Interdetector comparison of PDT and PHD for A = 143. PDT results are in good agreement even for detector Top I, but the energy range less wide.

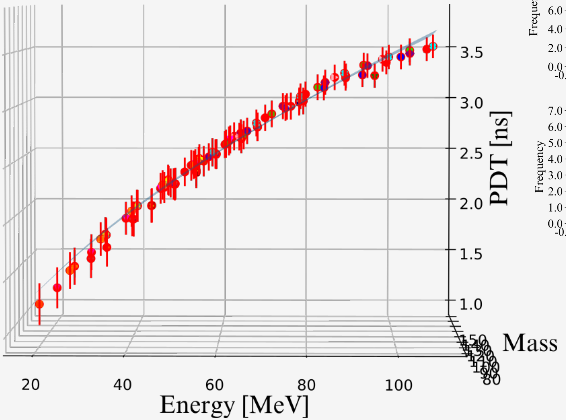


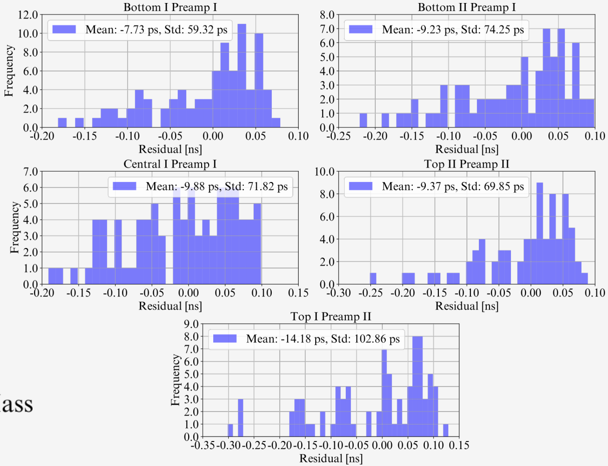


Results

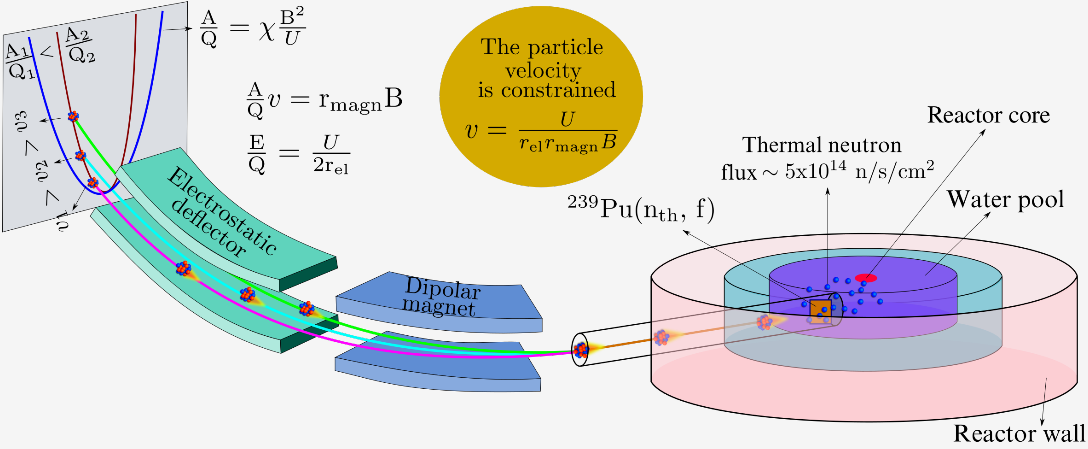
Modeling

$$PDT(A,E) = C \cdot A^{N_0} E^{N_1}$$





Experimental campaign at ILL
LOHENGRIN



Analysis
Combined ToF resolution

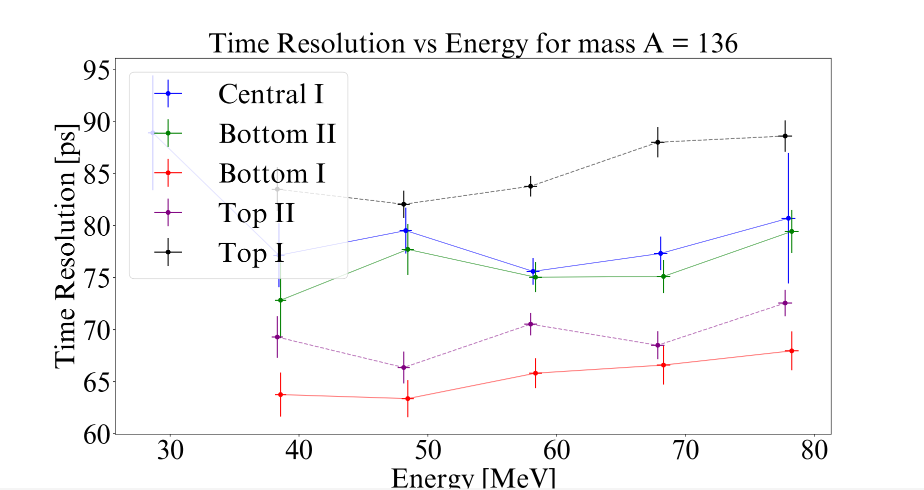


Figure: Inter-detector time resolution comparison for mass 136.

Analysis
Energy resolution

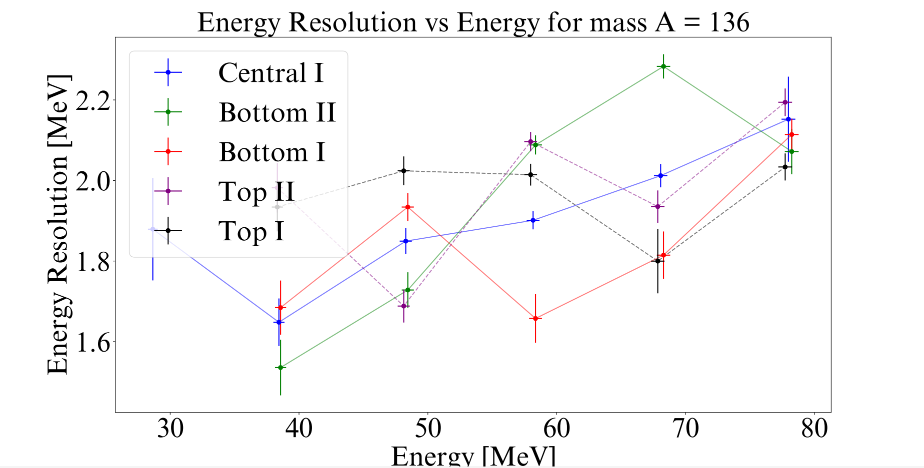


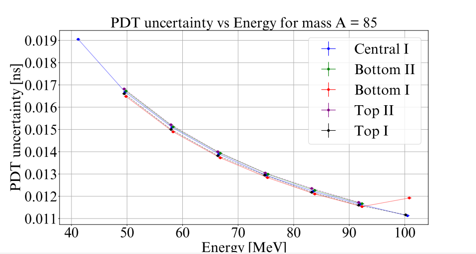
Figure: Inter-detector energy resolution comparison for mass 136

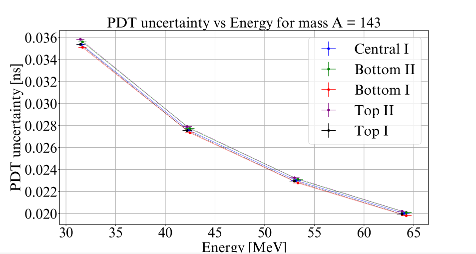
→ Energy losses were estimated performing simulations with GEANT4.

→ The G4 classes used in the simulations showed better agreement with experimental data.

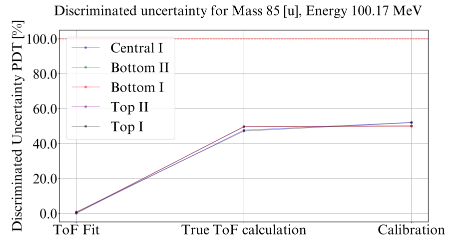
- → Energy losses were estimated performing simulations with GEANT4.
- → The G4 classes used in the simulations showed better agreement with experimental data.

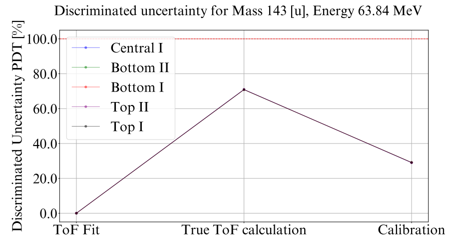
$$\Delta\ PDT \rightarrow \Delta\text{Gaussian fit} + \Delta\text{True ToF} + \Delta\text{Calibration}$$



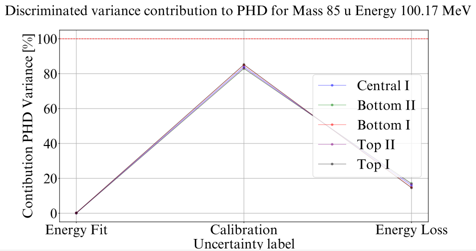


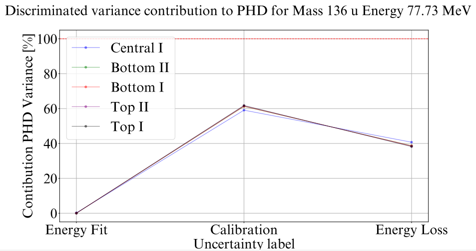
Results
Uncertainty estimation PDT





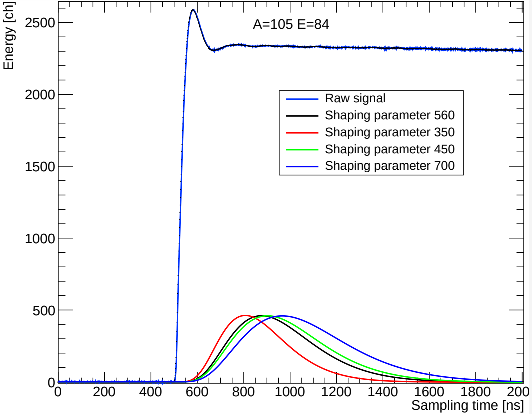
$$\Delta PHD \rightarrow \Delta\text{Gaussian fit} + \Delta\text{Calibration} + \Delta\text{Energy loss}$$

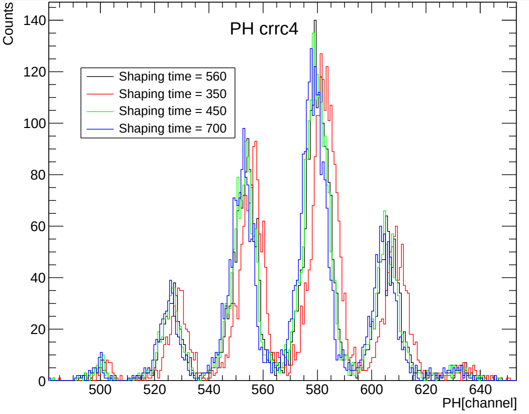


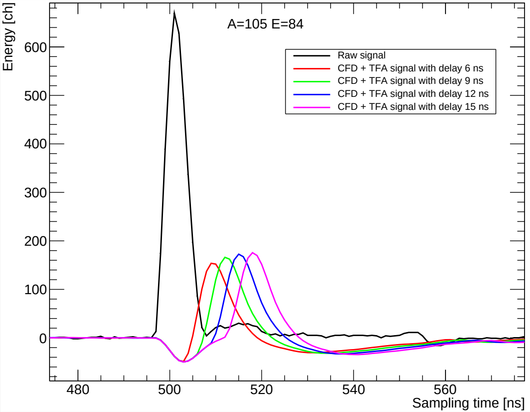


Digital Signal Processing

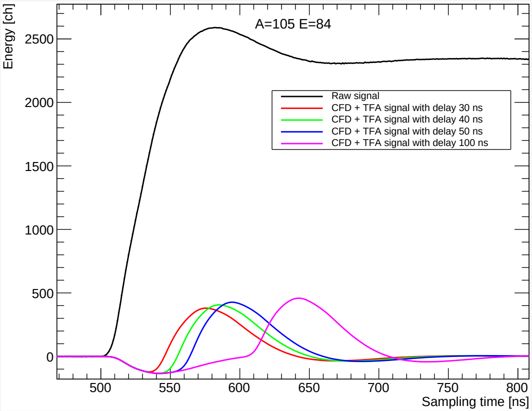
CRRC^4 filters were used to improve the energy spectrum resolution.







A=105 E=84
Raw signal
CFD + TFA signal with delay 6 ns
CFD + TFA signal with delay 9 ns
CFD + TFA signal with delay 12 ns
CFD + TFA signal with delay 15 ns
Energy [ch]
Sampling time [ns]
0
100
200
300
400
500
600
480
500
520
540
560



A=105 E=84
Raw signal
CFD + TFA signal with delay 30 ns
CFD + TFA signal with delay 40 ns
CFD + TFA signal with delay 50 ns
CFD + TFA signal with delay 100 ns
Energy [ch]
Sampling time [ns]
0
500
1000
1500
2000
2500
500
550
600
650
700
750
800

→ The particle identification was performed using a reference spectra with a change in the charge state in the LOHENGRIN setting.